MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2017/2018

EEE 3076 – POWER ELECTRONICS
(LE, EE, CE, NE)

16 OCTOBER 2017
9:00 AM – 11:00 AM
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 10 pages including cover page with 4 Questions only.
2. Answer ALL questions. All questions carry equal marks and the distributions of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

a) Using an aid of a BJT driver circuit and its current waveform, briefly explain how the gate/base driver circuit can improve switching speed for a switching power converter.

[7 marks]

b) A Power BJT (Motorola MJ16018 - Appendix A-1 and A-2) is used as a switch for a DC-DC converter connected to a resistive load. The input voltage is 250 V and maximum output current is 5 A. The switch is operated at 25 kHz with 50% duty cycle. Estimate the following for the case temperature of 25°C. (Note that, $\tau_{ON} = t_d + t_r$ and $\tau_{OFF} = t_s + t_f$)

(i) Static Loss

[6 marks]

(ii) Dynamic Loss

[9 marks]

(iii) Total Loss

[3 marks]

Continued...

Question 2

Design a full wave rectifier for a 20 kW resistive-inductive load. The application needs variable dc voltage to the load. You may need to select a suitable AC voltage for this application. Available AC voltage is 400V, 50Hz (for 3-phase system) and 230V, 50Hz (for 1-phase system).

a) Sketch the rectifier circuit diagram.

[4 marks]

b) Compute the maximum average load voltage.

[5 marks]

c) Sketch the voltage waveform across one of the switches. (use drawing sheet in appendix)

[6 marks]

d) What should be the minimum current and breakdown voltage for the switch used in the rectifier?

[4 marks]

e) Prove by calculation that the rectifier can produce dc voltage ranging from 200 V to 400 V to the load.

[6 marks]

Continued...

Question 3

a) Figure 3 (a) is a buck converter circuit. Design this converter to power a load that consumes 28 W to operate. Assume that the buck converter will be operating in the continuous current mode and all the components are ideal. The load requires a voltage with ripple not more than 1%. Following are other requirements :

Input voltage, $V_d = 10$ V, duty cycle, $D = 0.5$ and switching period, $T_s = 40\ \mu s$.

[13 marks]

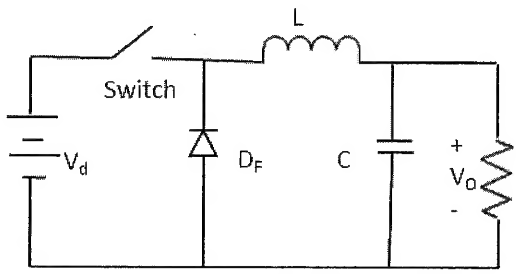

Figure 3 (a)

b) Consider a buck-boost converter as shown in Figure 3 (b) that supplies 120 W at 10 A from a 40 V DC source. The converter operates at the switching frequency of 10 kHz and given the inductor in the circuit is 250 μH. Determine the following:

(i) The duty cycle D.

[3 marks]

(ii) The minimum and maximum inductor current (I_{Lmin} , I_{Lmax}).

[4 marks]

(iii) The average input current.

[2 marks]

(iv) The average diode current.

[1 mark]

(v) Sketch the waveforms of the output voltage and the inductor current.

[2 marks]

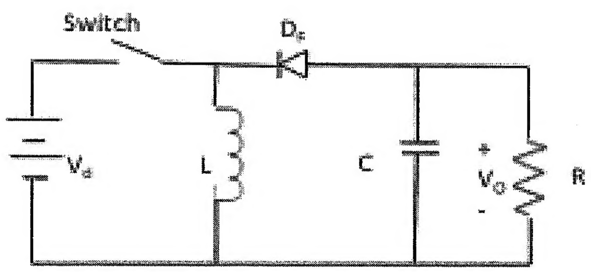

Figure 3 (b)

Continued...

Question 4

a) A pulse width modulated full bridge inverter produces output AC voltage as shown in Figure Q4(a). The inverter is operating at a duty cycle of 55 % with a frequency of 50 Hz. The resistive load is 12 Ω.

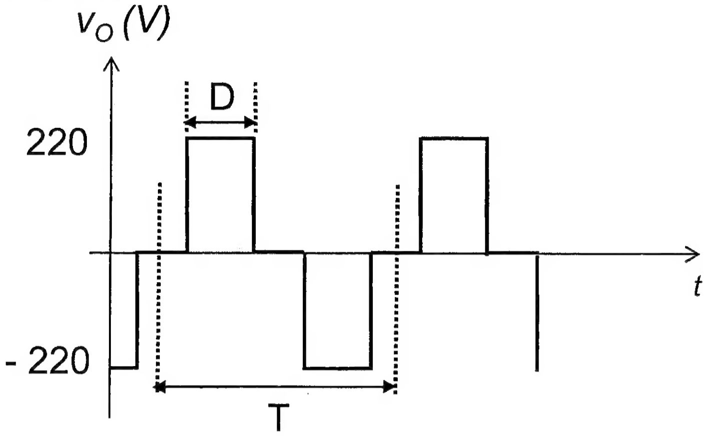

Figure Q4(a)

i) Calculate the r. m. s. value of output load current (i_o) and output load voltage (v_o) for the first, third, and fifth harmonics.

[7 marks]

ii) Show by calculation that the inverter can eliminate the third current harmonics at the load.

[4 marks]

iii) Calculate the total harmonic distortion (THD) of the output current for part (i) and (ii) above.

[8 marks]

b) A resonant inverter shown in Figure Q4(b) has the following circuit parameters: Show by calculation that the inverter operates in non-overlapping mode.

R = 2 Ω, L = 30 μH, C =17 μF, Output frequency = 2 kHz,

[6 marks]

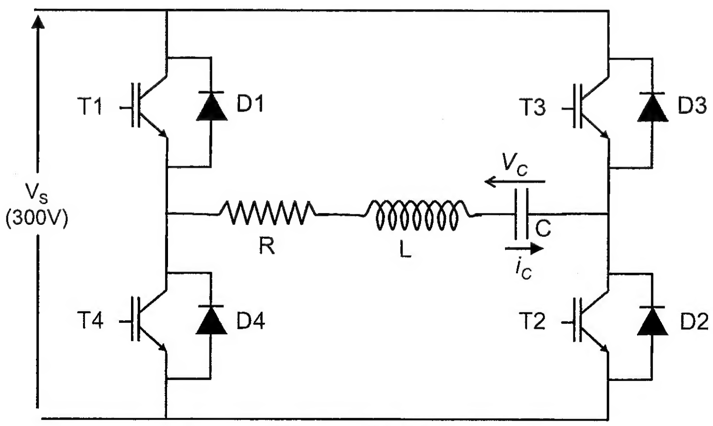

Figure Q4(b)

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Appendix A-1

MOTOROLA
SEMICONDUCTOR TECHNICAL DATA

Order this document
by MJ16018/D

MJ16018*
MJW16018*

*Motorola Preferred Device

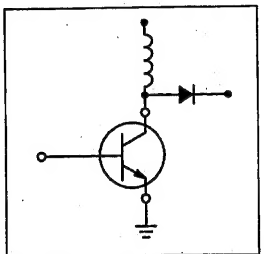
POWER TRANSISTORS
10 AMPERES
800 VOLTS
125 AND 175 WATTS

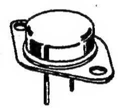
Designer's™ Data Sheet
NPN Silicon Power Transistors
1.5 kV SWITCHMODE Series

These transistors are designed for high–voltage, high–speed, power switching in inductive circuits where fall time is critical. They are particularly suited for line–operated switchmode applications.

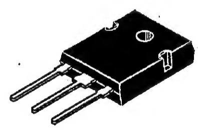
Typical Applications:
- Switching Regulators
- Inverters
- Solenoids
- Relay Drivers
- Motor Controls
- Deflection Circuits

Features:
- Collector–Emitter Voltage — V_{CEV} = 1500 Vdc
- Fast Turn–Off Times
  - 80 ns Inductive Fall Time — 100°C (Typ)
  - 110 ns Inductive Crossover Time — 100°C (Typ)
  - 4.5 µs Inductive Storage Time — 100°C (Typ)
- 100°C Performance Specified for:
  - Reverse–Biased SOA with Inductive Load
  - Switching Times with Inductive Loads
  - Saturation Voltages
  - Leakage Currents





CASE 1–07
TO–204AA
MJ16018



CASE 340F–03
TO–247AE
MJW16018

MAXIMUM RATINGS

Rating	Symbol	MJ16018	MJW16018	Unit
Collector–Emitter Voltage	$V_{CEO(sus)}$	800		Vdc
Collector–Emitter Voltage	V_{CEV}	1500		Vdc
Emitter–Base Voltage	V_{EB}	6		Vdc
Collector Current — Continuous — Peak(1)	I_C I_{CM}	10 15		Adc
Base Current — Continuous — Peak(1)	I_B I_{BM}	8 12		Adc
Total Power Dissipation @ T_C = 25°C @ T_C = 100°C Derate above T_C = 25°C	P_D	 175 100 1	 125 50 1	 Watts W/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–65 to 200	–55 to 150	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max		Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1	1	°C/W
Lead Temperature for Soldering Purposes: 1/8″ from Case for 5 Seconds	T_L	275		°C

(1) Pulse Test: Pulse Width = 5 µs, Duty Cycle ≤ 10%.

Designer's Data for "Worst Case" Conditions — The Designer's Data Sheet permits the design of most circuits entirely from the information presented. SOA Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

Preferred devices are Motorola recommended choices for future use and best overall value.

Designer's and SWITCHMODE are trademarks of Motorola, Inc.

REV 1

MOTOROLA

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Appendix A-2

MJ16018 MJW16018

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS(1)					
Collector–Emitter Sustaining Voltage (Table 1) (I_C = 50 mA, I_B = 0)	$V_{CEO(sus)}$	800	—	—	Vdc
Collector Cutoff Current	I_{CEV}				mAdc
(V_{CEV} = 1500 Vdc, $V_{BE(off)}$ = 1.5 Vdc)		—	—	0.25	
(V_{CEV} = 1500 Vdc, $V_{BE(off)}$ = 1.5 Vdc, T_C = 100°C)		—	—	1.5	
Collector Cutoff Current (V_{CE} = 1500 Vdc, R_{BE} = 50 Ω, T_C = 100°C)	I_{CER}	—	—	2.5	mAdc
Emitter Cutoff Current (V_{EB} = 6 Vdc, I_C = 0)	I_{EBO}	—	—	0.1	mAdc
SECOND BREAKDOWN					
Second Breakdown Collector Current with Base Forward Biased	$I_{S/b}$	See Figure 13			
Clamped Inductive SOA with Base Reverse Biased	RBSOA	See Figure 14			
ON CHARACTERISTICS(1)					
Collector–Emitter Saturation Voltage	$V_{CE(sat)}$				Vdc
(I_C = 5 Adc, I_B = 2 Adc)		—	—	1	
(I_C = 10 Adc, I_B = 5 Adc)		—	—	5	
(I_C = 5 Adc, I_B = 2 Adc, T_C = 100°C)		—	—	1.5	
Base–Emitter Saturation Voltage (I_C = 5 Adc, I_B = 2 Adc)	$V_{BE(sat)}$	—	—	1.5	Vdc
(I_C = 5 Adc, I_B = 2 Adc, T_C = 100°C)		—	—	1.5	
DC Current Gain (I_C = 5 Adc, V_{CE} = 5 Vdc)	h_{FE}	4	—	—	—
DYNAMIC CHARACTERISTICS					
Output Capacitance (V_{CB} = 10 Vdc, I_E = 0, f_{test} = 1 kHz)	C_{ob}	—	—	450	pF

SWITCHING CHARACTERISTICS

Characteristic	Conditions		Symbol	Min	Typ	Max	Unit
Inductive Load (Table 1)							
Storage Time	Baker Clamped (I_C = 5 Adc, I_{B1} = 2 Adc, $V_{BE(off)}$ = 2 Vdc, $V_{CE(pk)}$ = 400 Vdc) PW = 25 μs	(T_J = 25°C)	t_{sv}	—	4000	8000	ns
Fall Time			t_{fi}	—	60	200	
Crossover Time			t_c	—	90	300	
Storage Time		(T_J = 100°C)	t_{sv}	—	4500	9000	
Fall Time			t_{fi}	—	80	250	
Crossover Time			t_c	—	110	375	
Resistive Load (Table 1)							
Delay Time	Baker Clamped (I_C = 5 Adc, V_{CC} = 250 Vdc, I_{B1} = 2 Adc, I_{B2} = 2 Adc, R_{B2} = 3 Ω, PW = 25 μs, Duty Cycle ≤ 2%)		t_d	—	85	200	ns
Rise Time			t_r	—	900	2000	
Storage Time			t_s	—	4500	9000	
Fall Time			t_f	—	200	400	

(1) Pulse Test: PW = 300 μs, Duty Cycle ≤ 2%.

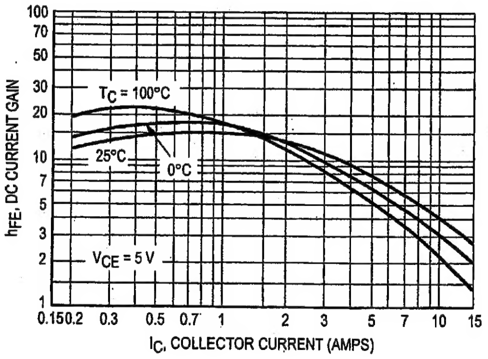

Figure 1. DC Current Gain

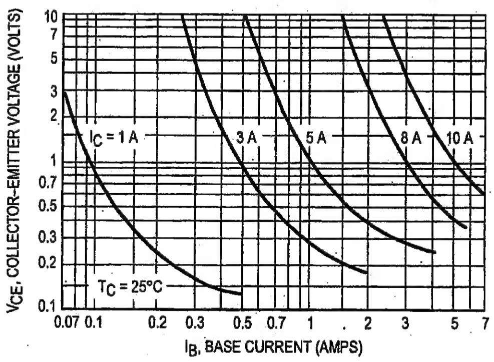

Figure 2. Collector Saturation Region

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Examination Formula Sheet (Rev 4.0)

AC-DC Converters

Single Phase Uncontrolled Rectifiers (Half wave) , R load	Single Phase Uncontrolled Rectifiers (Half wave), RL Load
$V_{o,avg} = \frac{\sqrt{2}V_{S,rms}}{\pi}$, $V_{o,rms} == \frac{V_{S,rms}}{\sqrt{2}}$	$V_{o,avg} = \frac{\sqrt{2}V_{s,rms}}{2\pi}[1-\cos(\beta)]$ $V_{o,rms} = \frac{V_{s,rms}}{\sqrt{2\pi}}\sqrt{\beta - \frac{\sin 2\beta}{2}}$ $\beta \approx \pi + \theta$,$\theta = \tan^{-1}\left(\frac{\omega L}{R}\right)$
Single Phase Uncontrolled Rectifiers (Bridge Full wave)	Three Phase Uncontrolled Rectifiers (Half wave)
$V_{o,avg} = \frac{2\sqrt{2}V_{s,rms}}{\pi}$, $V_{o,rms} = V_{s,rms}$	$V_{o\_avg} = \frac{3\sqrt{3}V_{l-n}}{\sqrt{2}\pi}$, $V_{0\_rms} = 1.19V_{l-n}$
Three Phase Uncontrolled Rectifiers (Full wave)	Single Phase controlled Rectifiers (Half wave)
$V_{0\_avg} = \frac{3\sqrt{2}V_{l-l}}{\pi}$, $V_{0\_rms} = 0.963\ V_{l-l}$	$V_{0\_avg} = \frac{V_{S,rms}}{\sqrt{2}\pi}(1+\cos\alpha)$ R Load $V_{0\_avg} = \frac{V_{S,rms}}{\sqrt{2}\pi}(\cos\alpha + \cos\beta)$ RL Load
Single Phase controlled Rectifiers (Bridge Full wave)	Three Phase controlled Rectifiers (Half wave)
$V_{0\_avg} = \frac{\sqrt{2}V_{S,rms}}{\pi}(1+\cos\alpha)$ R Load $V_{0\_avg} = \frac{2\sqrt{2}V}{\pi}\cos\alpha$ RL Load	$V_{0\_avg} = \frac{3\sqrt{2}}{2\pi}V_{AN}\left(1+\cos\left(\pi/6+\alpha\right)\right)$
Three Phase controlled Rectifiers (Full wave)	
$V0\_avg = \frac{3\sqrt{6}}{\pi}V_{AN}\cos\alpha$	

DC-DC Converters

Buck Converter (CCM)	Buck Converter (DCM)
$V_o = DV_d$ $I_{L\max} = V_o\left[\frac{1}{R} + \frac{(1-D)}{2Lf_s}\right]$ $I_{L\min} = V_o\left[\frac{1}{R} - \frac{(1-D)}{2Lf_s}\right]$	$\frac{V_o}{V_d} = \frac{D}{D+\Delta_1}$ $I_o = \frac{V_d T_s}{2L}D\Delta_1$

Continued…

DC-DC Converters (cont.)

Boost Converter (CCM)	Boost Converter (DCM)
$V_o = \frac{V_d}{1-D}$ $I_{L\max} = \frac{V_d}{(1-D)^2 R} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d}{(1-D)^2 R} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{\Delta_1 + D}{\Delta_1}$ $I_o = \frac{V_d T_s}{2L} D \Delta_1$
Buck-Boost Converter (CCM)	**Buck-Boost Converter (DCM)**
$V_o = \frac{V_d D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2} + \frac{V_d D T_s}{2L}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2} - \frac{V_d D T_s}{2L}$	$\frac{V_o}{V_d} = \frac{D}{\Delta_1}$ $I_o = \frac{V_d D}{2 f_s L}(D + \Delta_1) - \frac{D I_o}{\Delta_1}$
Flyback Converter (CCM)	**Flyback Converter (DCM)**
$\frac{V_o}{V_d} = \frac{N_2}{N_1} \frac{D}{1-D}$ $I_{L\max} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 + \frac{V_d D T_s}{2L_m}$ $I_{L\min} = \frac{V_d D}{R(1-D)^2}\left[\frac{N_2}{N_1}\right]^2 - \frac{V_d D T_s}{2L_m}$	$\frac{V_o}{V_d} = D\sqrt{\frac{R}{2 f_s L_m}}$ $I_o = \frac{V_o}{R}$

DC- AC Converters

Single-Phase Half-bridge Inverter with RL load	Resonant Converters
$v_o(\omega t) = \sum_{n=1,3,5,....}^{\infty} \frac{2V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Square Wave) $v_o(\omega t) = \sum_{n=1,3,5,....}^{\infty} \frac{4V_s}{n\pi}\sin(n\omega t)$ Single-phase full-bridge PWM inverter (Quasi Square Wave) $v(\omega t) = \sum_{n=1,3,5...}^{\infty} \frac{4V_s}{n\pi}\sin\frac{nD\pi}{2}\cos n(\omega t - \frac{D\pi}{2})$	$\omega_r = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ $i(t) = \frac{V_s + V_c}{\omega_r L} e^{-\alpha t}\sin\omega_r t$, $\alpha = \frac{R}{2L}$ $V_c = V_s\left(\frac{e^{2z}-1}{e^{2z}+1}\right)$, $z = \frac{\alpha\pi}{\omega_r}$ $V_{cp} = V_s\left(1 + \frac{2e^{2z}}{e^{2z}+1}\right)$

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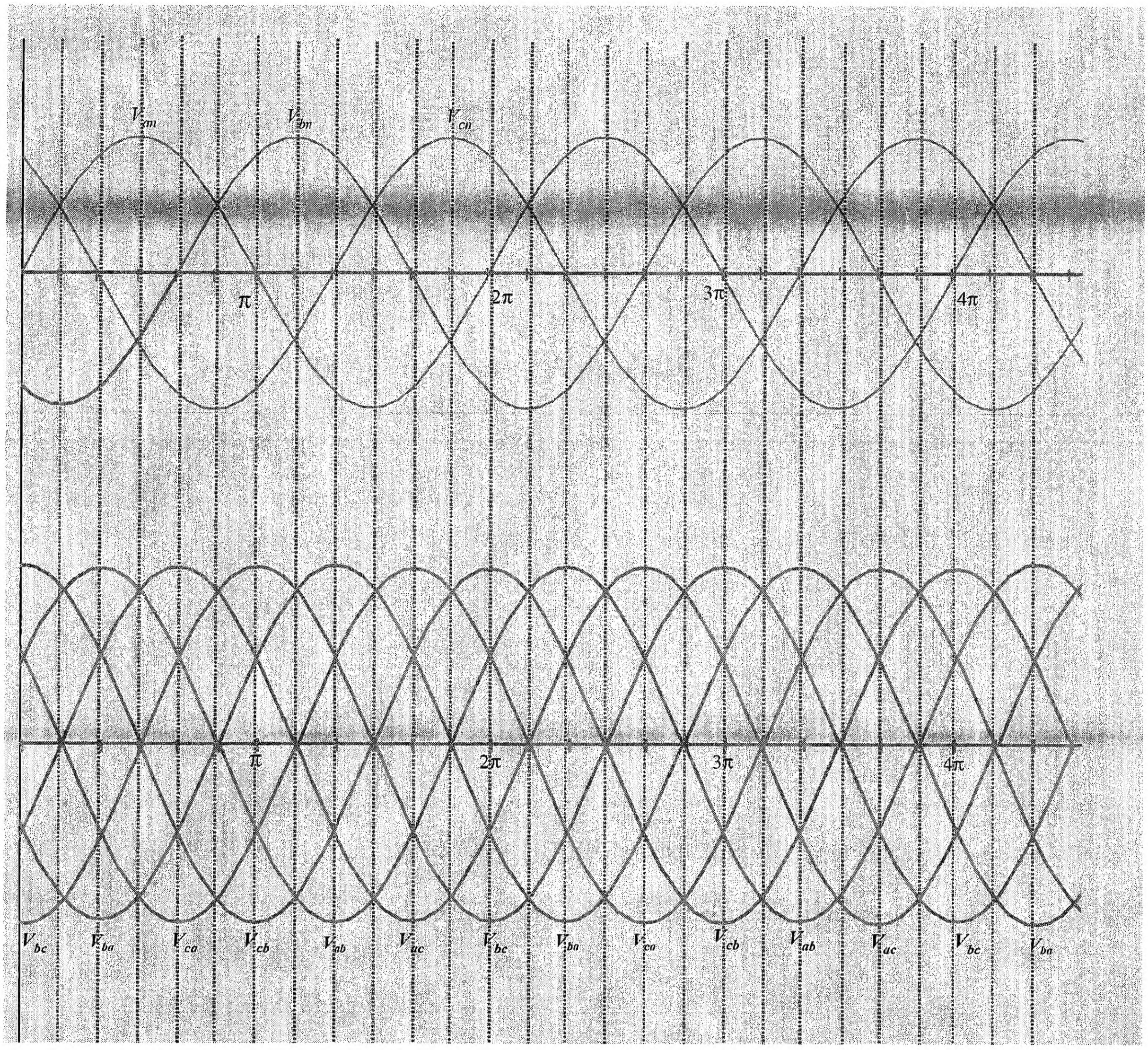
Appendix (For Question 2(c))- Please attach to the answer booklet

Student ID : …………………………..…..….. Table No.:…………



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